Soil-structure interaction analysis of multi-story building

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ABSTRACT

This paper focuson the implementation of 2-D finite element model of reinforced concrete frame and pile foundation system incorporating the soil interaction. Three-node isoparametric beam elements with three degrees of freedom per node is used to model the superstructure members, and eight node isoperimetric quadrilateral element is utilized to simulatethe soil behavior. The applicability of this model was demonstrated by analyzing a six storeys building. The results have shown that the soil interaction has a significant effects on the response of the structure.

Keywords: Reinforced concrete frame, Soil structure interaction, Finite element analysis.

1. Introduction

Soil-structure interaction (SSI) is the response of the soil influences the motion of the structure and the effect of the structure behavior on the soil response. Therefore, the analysis of Piled-Foundation is very challenging because the load in the piled- structures is transferred to the soil not only by the interaction between the soil and the piles but also by the interaction between foundation structure and superstructure (Sunny & Mathai, 2017).

2. Research background

In this section critical review of reported literature due to the soils structure interaction are discussed;

Hussein and Meguid implemented two and three dimensional (2D & 3D) fixed element analyses using ABAQUS software to study two different soil structure interaction problems. 3D analysis of unconfined and confined soil with an example of a square footing over geogrid reinforced soil, 2D plane strain analysis of a box culvert pick up by EPS geofoam modulation to minimize earth pressure on the walls of the structure. In the presented study the numerical results were compared with experimental data. It has been concluded that the effectiveness of using the fixed element method to solve these classes of geotechnical engineering problems(Hussein &Meguid, 2013)

Samangany and his co-authors presented a static and dynamic analysis of the storage tanks by taking into account the interaction of soil and structure. In this work the effect of soil type on seismic behavior of structure has been studied considering three kinds of soil with different parameters (soft, middle and hard soil). In the present paper, three dimensional cubic storage tanks modelled using Abaqus software and energy absorbent boundaries method has been used to model waves propagation in boundaries. The results have shown that soil type has considerable effect on soil and structure interaction where the stresses were increased of different points of structure in wall of the tank for soft soils compared with other soil types (Samangany et al. 2013).

In order to evaluate the effect of soil structure interaction (SSI) on the performance of structure during the earthquakes, the mechanism of the energy transferring from soils to structure was investigated using Abaqus software by Tomal and his co-authors. In the presented study a wave-soil-structure interaction analysis was carried out for buildings subjected to external harmonic loadings and earthquake loadings using three different parametric studies.The response of the structure with and without SSI was compared. The results have shown that, a considerable difference was noticed in response of structure considering effect of SSI (Tomal et al, 2014).

Malviya and Singh (2017) focused on the soil structure interaction behavior of three stories RCC frame building constructed over shallow footing below a base of dense soil. In this study, the finite element method considering the direct method was applied to model the soil structure interaction by using ABAQUS. The horizontal deformation and vertical deformation of the RCC building was estimated under static and dynamic loading. The perfectly elastic plastic constitutive model has been used to model the stress behavior of the soil. The static loading under gravity and 0.1g horizontal ground acceleration respectively was used for the analysis. The results indicated that the soil structure interaction has an important role to assess the behavior of any structure with the various base of footing or foundation.

Yang et al. (2008) formulated the substructure method based on the wave propagation theory and the lumped-mass explicit finite element procedure with a local transmitting artificial boundary using a step-by-step integration and central difference approach. Different numerical examples were studied to evaluate the efficacy of the proposed procedure. First case is structure on a rigid foundation which is on the surface of semi-infinite soil medium and second case is studied for the influence by the big stiffness of soil medium on the dynamic characters of the soil-structure system. The soil-structural dynamic predictions for the two cases using the proposed substructure method were in good agreement to the reference solutions by direct and atypical method.

Ravishankar& Satyam (2013) developed a numerical model of a tall building and unbounded soil by using the Finite-Element Method, which naturally satisfies the radiation condition for the wave propagation problem. In this research paper the dynamic analysis was carried out based on Bhuj ground motion data (2001, magnitude of 7.7) and a homogeneous soil strata was assumed. The SSI response was studied for both pile and raft foundation systems. It has been observed that for the same soil strata displacements and stresses in case of pile foundation system is comparatively less than raft foundation system.

Matinmanesha & Asheghabadib (2011), presented a seismic analysis of soil-structure interaction using finite element method. In the presented paper, two different sandy soils (dense and loose sand) were considered as the hypothetical site soil in order to investigate the effect of sandy soil properties on the seismic response of the soil-structure system. The results has concluded that all soil types increase bedrock motions in the soil-structure interface but with different degrees based on many factors the soil such as type and properties, earthquake frequency content and the properties of the overlying building.

3. Computer Code

In order to achieve the study objectives,the finite element code which was developed by (A. A. Abdulrazeg, 2013), has been used in the present study.

4. Problem Analyzed

In the present study the six storeysplan frame with pile foundation has been selected as case study. The frame is 19m high with 4×2 bay (4m×4m in plan). The height of the first floor is 4 m and the other storeys is 3m. Table 1 shows the soil properties.

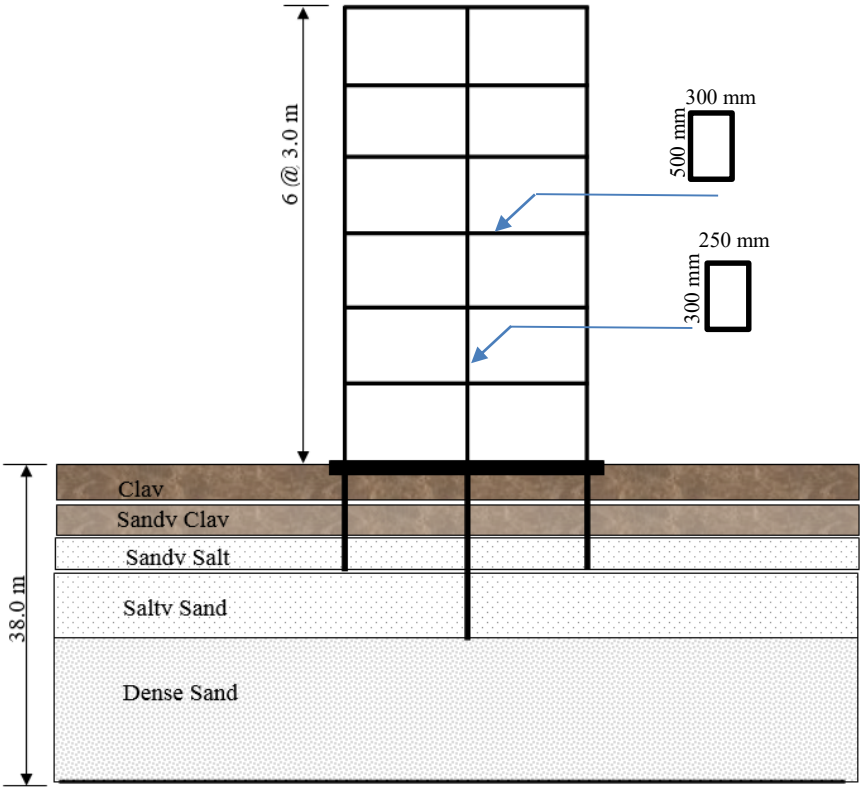


Figure 1. Building with Soil

Table 1:*Summary of Soil Properties*

Description	Clay	Sand Clay	Sand slit	Dense Sand
Modules of elasticity	25000 kN/m²	45000 kN/m²	50000 kN/m²	150000 kN/m²
K modulus number	200	200	200	198
n, Exponent	0.98	0.995	0.9	0.82
R_f, Failure ratio	0.846	0.88	0.875	0.855
C, cohesion	10 KN / m²	22 KN / m²	21 KN / m²	70 KN / m²
Φ, Angle of friction	4	19	19	22

5. Proposed Physical Model

For the Geometry modelling of reinforced concrete frame and pile foundation system the following elements are utilized as shown in figure 3:

i. Eight node conventional parabolic finite element to represent the abutment, and the soil mass shown in figure 1 (Noorzaei et al. 2010).
ii. Three node isoparametric beam bending element with three degrees of freedom per node to represent the superstructure and pile shown in figure 2. This beam element takes into account the effect of transverse shear forces and axial-flexural interaction (Noorzaeiet et al. 2010).

The two-dimensional serendipity types of finite Element and beam element along with their shape functions are presented in Table 2.

Table 2: Shape functions for elements were used in idealization of the structure

Type of element	Shape functions
8-node finite element	For corner nodes: $N_i = \frac{1}{4}(1+\xi\xi_i)(1+\eta\eta_i)(\xi\xi_i+\eta\eta_i-1)$ For midside nodes: $N_i = \frac{\xi_i^2}{2}(1+\xi\xi_i)(1+\eta^2)+\frac{\eta_i^2}{2}(1+\eta\eta_i)(1+\xi^2)$
3-node isoparametric beam bending element	$N_1 = -\frac{1}{2}\xi(1-\xi)$ $N_2 = (1-\xi^2)$ $N_3 = -\frac{1}{2}\xi(1+\xi)$

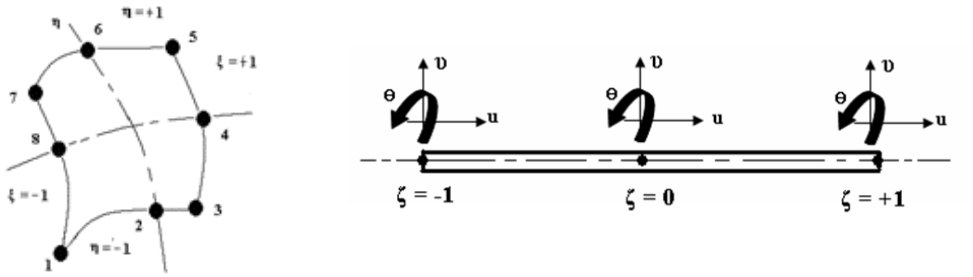


Figure 2. Parabolic isoperimetric Elements

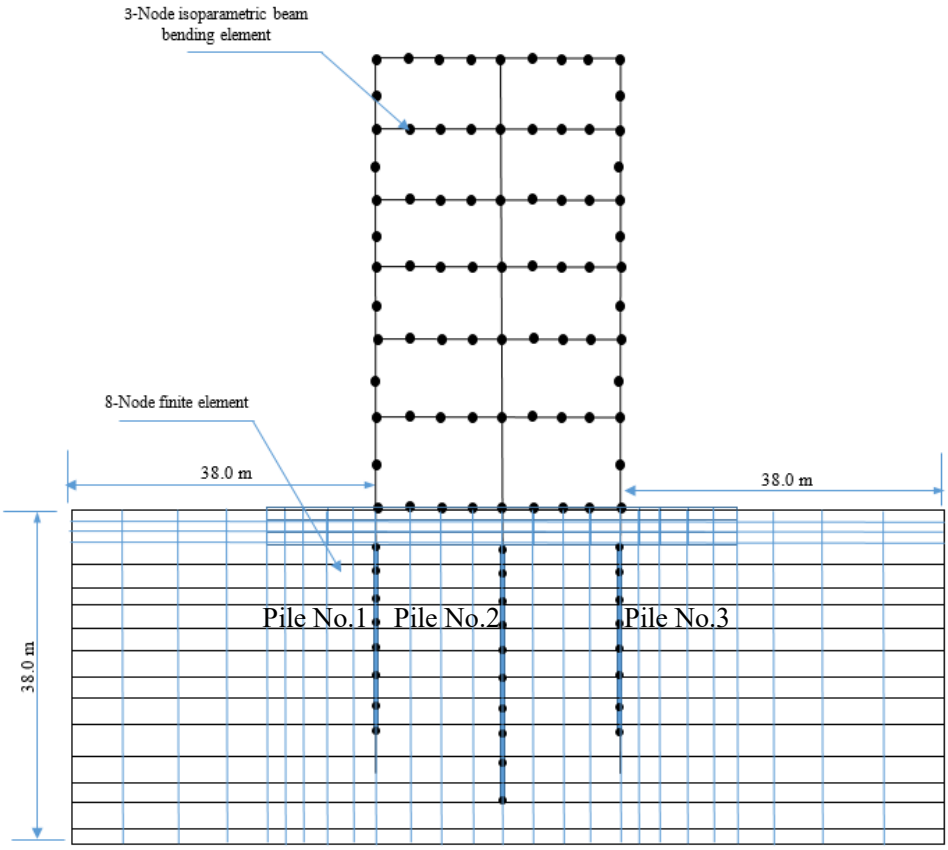


Figure 3. Finite Element Modeling Structure- Mat Foundation- Pile/ Soil

6. Result and Discussion

In this section, results from structural analyses performed on a numerical model of the structure-foundation- Pile and soil for the two load combinations (dead and live load + dead and wind load) are presented. The response and behaviour of system was discussed regarding to the difference displacement and stresses.

Figure 4. (a), (b), show the Contour of displacement of soil for both load combinations. From the plots it can be seen that, the movement of the soil will be effected by the foundation movement.

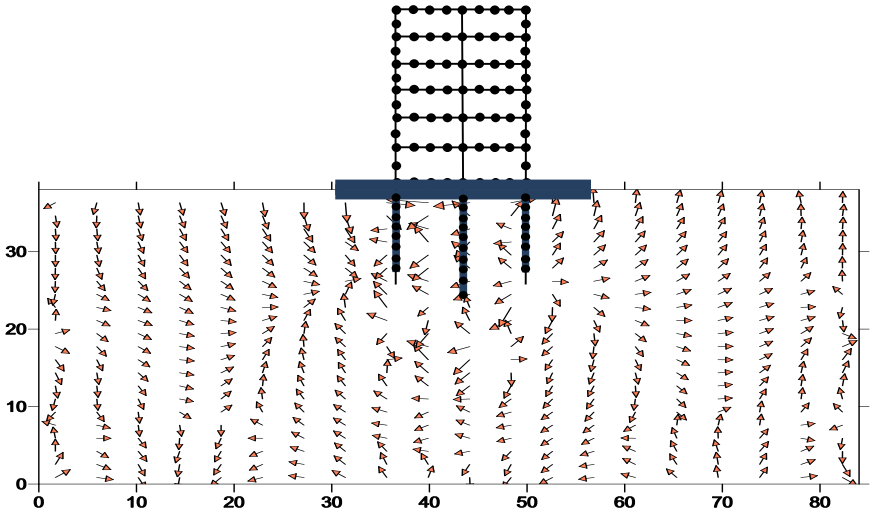


Figure 4(a). Contour of displacement for first load combination (dl+ ll)

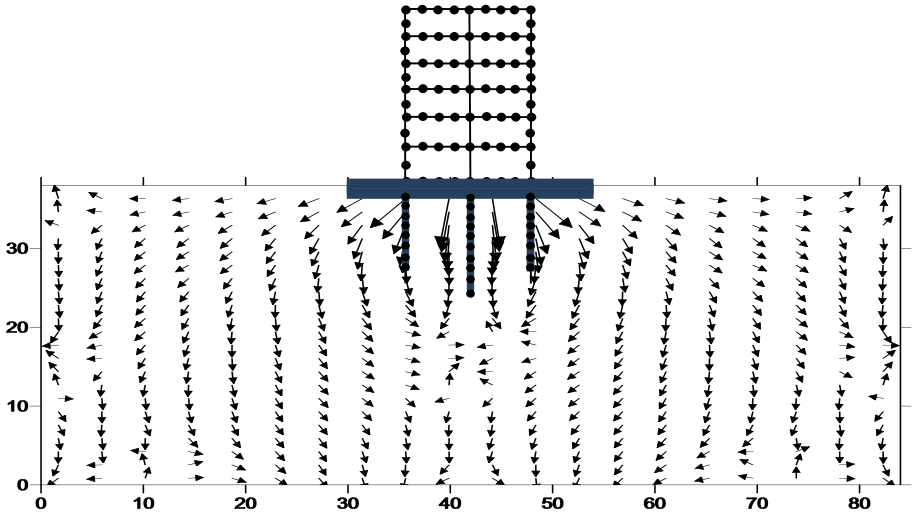
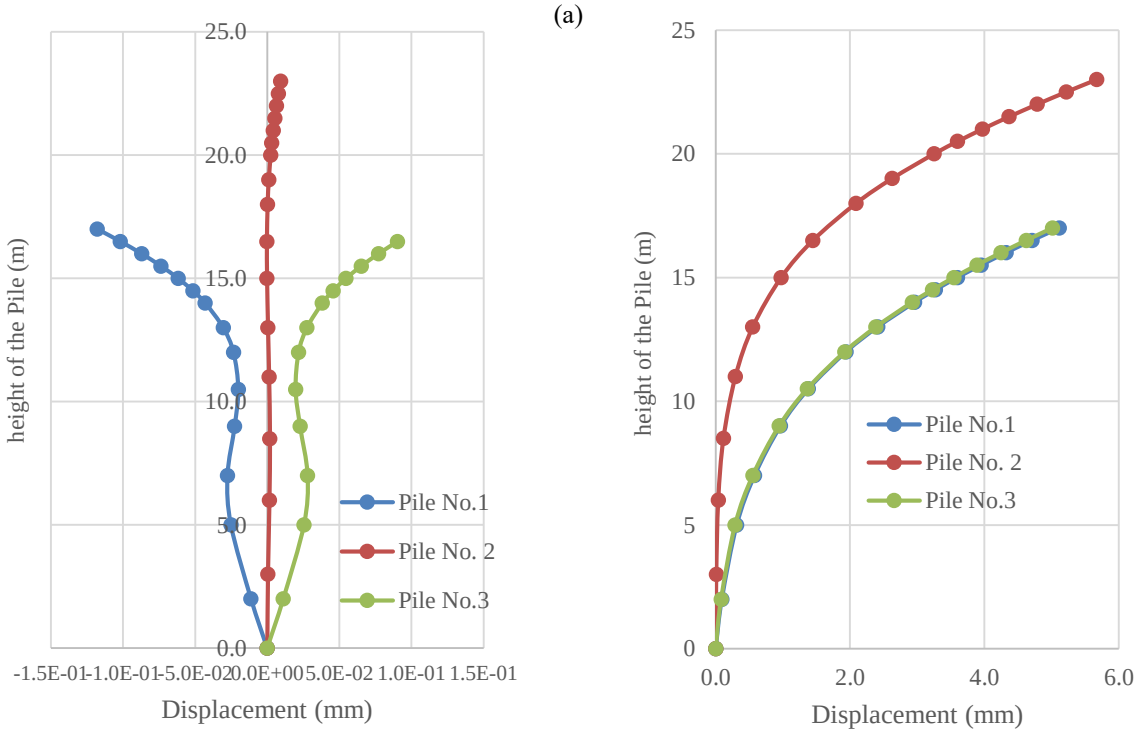


Figure 4(b). Contour of displacement for second load combination (dl+ wind)

Where the shear force is developed at the top of pile due to movement of abutment, the pile will move to other direction .The surrounding soil will move consequently in the same direction of pile's movement . Figure 5, show the displacement of pile for various load combinations.

Deformation of pile depends in many factors such as; the load combination and the position of load along the slab. The lateral movement of pile not only because of lateral load, lateral movement can be caused by the vertical load as well.

(a)



First load Combination (dl+ll) Second load Combination (dl+wind)

Figure 5. Lateral movement of piles

Figure 6 (a), (b), show the Contour of variation σx of soil for both load combinations.From the plots it can be seen that, the stress concentration on the soil in this type of loading (vertical load), will be concentrate at the bottom of pile where the movement of pile will try to push the soil back. The concentration of compression stresses is under the piles as the load is distributed. Figure 6 (b) shows that the tension stresses will be developed on the left pile and compression on the right side and this attributed to the wind load as it push the building from the left to the right.

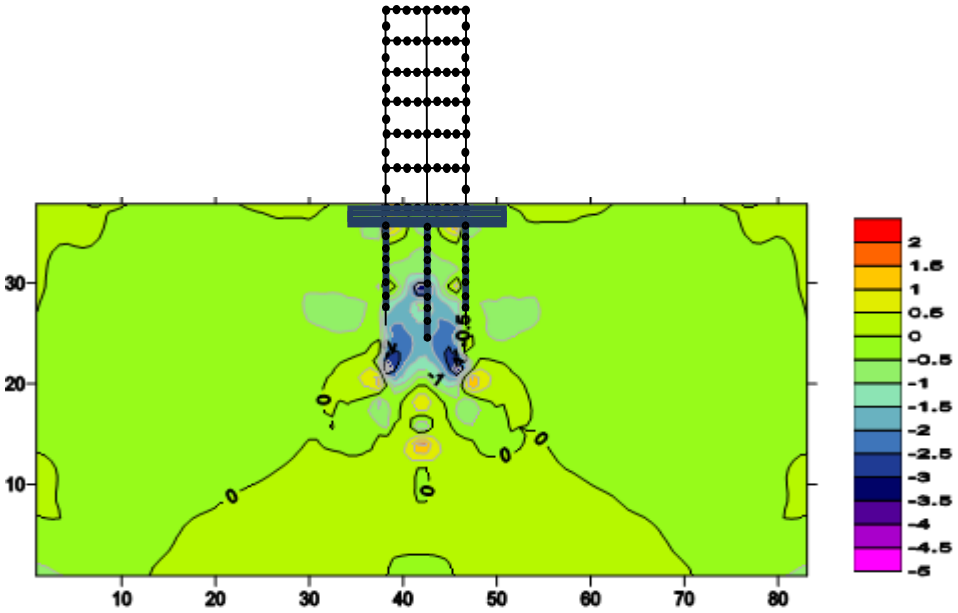


Figure 6 (a): Contour of variation σx(First load combination)

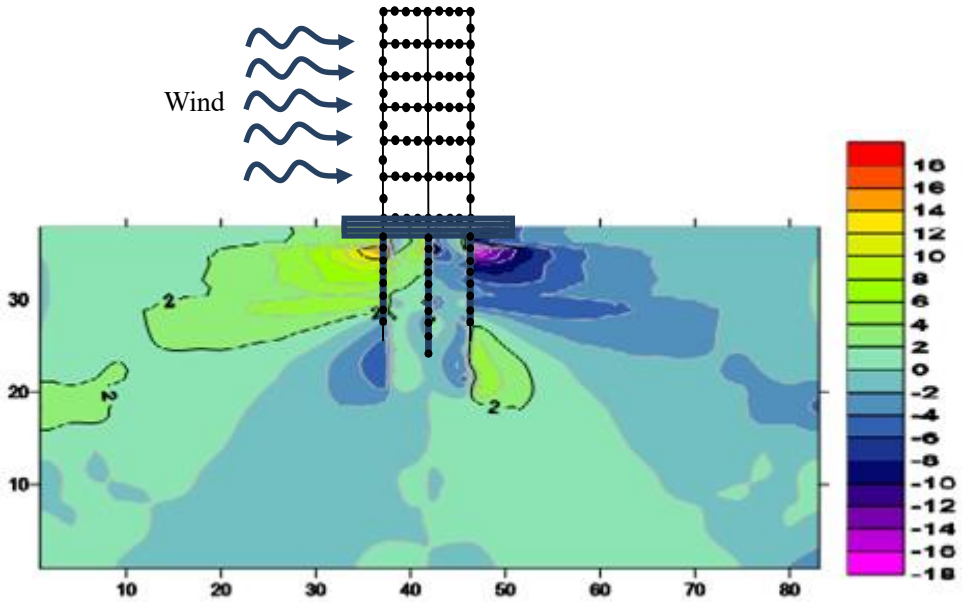


Figure 6 (b): Contour of variation σx (Second load combination)

7. Acknowledgment

Based on the work in this project, the following conclusions are drawn

- Soil type has considerable effect on soil and structure interaction where the stresses concentration are influenced by different types of soil.
- The nonlinearity of the soil has a significant effect on the response of the structure. Therefore, more accurate constitutive material model is required for more realistic results.
- There was a considerable difference in response of the structure if the effect of SSI is considering.
- Soil amplifies bedrock motions in the soil-structure interface with different degrees based on the soil type and properties, earthquake frequency content and the properties of the overlying building.
- The results show that the movement of the soil around the pile significantly affected by the applied load on the abutment. The moving ground does not provide resistance to movements of the abutment, as the soil move same direction with pile

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